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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A D-C VACUUM-TUBE VOLTMETER

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●**CIRCUIT DESIGN AND TESTING** in radio and electronic equipment involves the measurement of a number of d-c voltages, ranging in magnitude from a fraction of a volt to several thousand volts, associated with impedance from a few ohms to many megohms. The advantage of using a vacuum-tube voltmeter for these measurements is the assurance that no power is drawn from the circuit under test and hence that the indicated voltage is the actual circuit voltage. The TYPE 728-A D-C Vacuum-Tube Voltmeter shown in Figure 1 maintains this advantage over a voltage range of approximately 60,000:1. The minimum voltage that can be measured with this meter is 0.05 volt, and the maximum is 3000 volts. For voltages up to 30 volts the input resistance is over 5000 megohms; for voltages above 30, it is 1000 megohms. Operated from internal batteries, it is a companion instrument to the TYPE 727-A Vacuum-

FIGURE 1. View of the TYPE 728-A Vacuum-Tube Voltmeter with cover open.

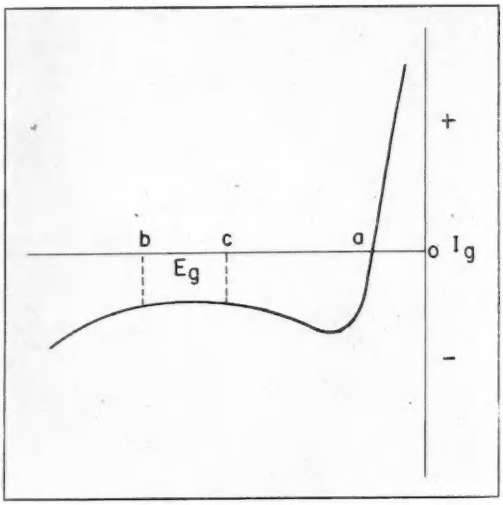


FIGURE 2. Typical grid current characteristic for the amplifier tube.

Tube Voltmeter,[1] for a-c voltage measurements up to 100 megacycles and the TYPE 729-A Megohmmeter[2] (2000 ohms to 50,000 megohms). These three meters comprise a group of small, portable, accurate instruments for use in the laboratory or in the field where power lines are not accessible.

An analysis of the input circuit of a d-c vacuum-tube voltmeter discloses that grid current[3] in the amplifier tube must be kept at a minimum to obtain high input resistance, but of equal importance is the leakage path between input terminals due to wiring, anchor terminals, switches, etc. Here, a choice of materials that maintain high resistance in the face of adverse humidity[4] conditions is imperative. The grid current in the amplifier tube is a function of tube type, operating conditions, and circuit arrangement. If the grid current of an individual tube is plotted against grid bias, a curve of the general shape shown in Figure 2 will be obtained. It will be noted that at one point (*a*) there is no grid current, and the input resistance, in so far as grid current is concerned, is infinite. But, to operate the tube over a range of input voltage, the grid bias must change. It is therefore advisable to select a suitable range over which the bias change occurs and, as is done in the circuit of the TYPE 728-A D-C Vacuum-Tube Voltmeter, to introduce a large amount of degeneration in order to limit the required bias increment (e.g., *b* to *c* in the figure) and so to prevent operation over a region of high grid current.

Over the three lower voltage ranges of the TYPE 728-A D-C Vacuum-Tube Voltmeter (0–3, 0–10, and 0–30 volts), the input terminals are connected directly to the open grid of the tube. While manufacturing controls assure an input resistance in excess of 5000 megohms, the usual input resistance is about 20,000 megohms. This high resistance has an interesting effect which may at first seem strange: if a potential of, say, ten volts is applied to the input terminals and then removed, the meter will continue to indicate the ten volts for perhaps a minute or longer. This occurs because the capacitance from grid to ground becomes charged and, in view of the very large leakage resistance, it simply takes time for the capacitor to discharge ($RC = 10{,}000 \times 10^6 \times .01 \times 10^{-6} = 100$ seconds). Of course, as soon as the input terminals are shorted, or shunted with the external circuit under test, the meter reading drops to zero or to the value of the potential being measured.

To extend the voltage range upward, a voltage divider is switched between high-voltage terminals and the vacuum-tube voltmeter circuit. The input resistance of the instrument for the 0–100, 0–300, 0–1000, and 0–3000 volt ranges is 1000 megohms. The choice, treatment,

adjustment, and mounting of the resistors used for such a high-voltage divider are of paramount importance. There are considerations of voltage and temperature coefficient, of aging and moisture proofing. The resistors in the TYPE 728-A Voltmeter were carefully selected with all of these considerations in mind. They are spirally grooved and, before final selection, are subjected to artificial aging cycles and to impregnation.

In addition to the major design considerations, various features have been incorporated to increase the usefulness of the instrument. An R-C filter permits the measurement of d-c voltages in spite of superimposed a-c potentials as high as 200 volts. A polarity switch obviates the necessity of transposing meter connections and, when desirable, permits grounding either pole to the meter panel. This is extremely useful when checking an electronic circuit where various potentials of different polarity to ground must be determined. All batteries are contained in the small cabinet, and a simple switch manipulation determines the battery condition and warns the operator when the batteries must be replaced, whether because of low voltage or excessive battery resistance. To safeguard the batteries, the power switch is automatically turned off when the instrument cover is closed.

The TYPE 728-A D-C Vacuum-Tube Voltmeter fills the need for a voltmeter of very high input resistance that can be used for checking small tube bias potentials or high cathode-ray accelerating voltages, automatic volume control, or automatic frequency control circuits, f-m discriminator circuits or, in general, the d-c voltages that appear in any setup in the laboratory or in the field. Furthermore, these voltages can be measured with the assurance that the input resistance of the voltmeter will cause no error.

— A. G. BOUSQUET

REFERENCES

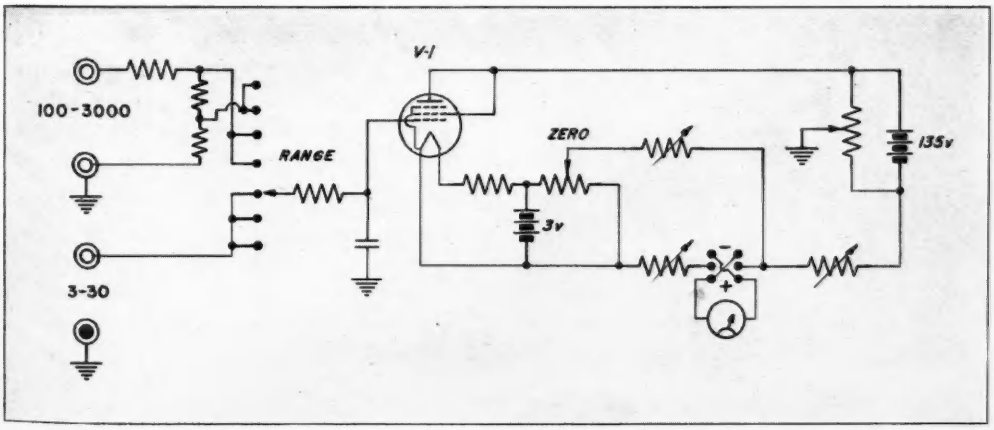
1. W. N. Tuttle, "The Type 727-A Vacuum-Tube Voltmeter," General Radio *Experimenter*, Vol. XVI, No. 12, May, 1942.

2. W. N. Tuttle, "A Portable Megohmmeter," General Radio *Experimenter*, Vol. XV, No. 2, July, 1940.

3. W. B. Nottingham, "Measurement of Small D-C Potentials and Currents in High Resistance Circuits by Using Vacuum Tubes," Journal of the Franklin Institute, Vol. 209, No. 3, March, 1930, pp. 287–348.

4. R. F. Field, "The Effect of Humidity on Electrical Measurements," General Radio *Experimenter*, Vol. XVIII, No. 3, August, 1943.

FIGURE 3. Schematic circuit diagram of the TYPE 728-A Vacuum-Tube Voltmeter.



SPECIFICATIONS

Range: 0.05 to 3000 volts in seven ranges (3, 10, 30, 100, 300, 1000, 3000 volts, full scale).

Accuracy: Within ±3% of full scale for the lower voltage ranges (3, 10, 30 volts, full scale). Within ±5% of full scale for the higher voltage ranges (100, 300, 1000, 3000 volts, full scale). Battery aging may cause an additional error of 2% of full scale on the 3-volt range.

Input Resistance: 1000 megohms on the higher voltage ranges (100, 300, 1000, 3000 volts, full scale). Greater than 5000 megohms on the low voltage ranges.

Terminals: Two sets of input terminals are provided on the panel. One set is used for measurements at the low voltage end of the range (0 to 30 volts) and the other set is used for the higher voltage measurements (30 to 3000 volts).

Polarity: A reversing switch on the panel permits measurements with either the positive or the negative terminal of the source grounded to the panel of the instrument.

Effect of A-C: A superimposed a-c voltage of as high as 200 volts has a negligible effect on the meter indication.

Tube: The tube, a type 1E5-GP, is supplied.

Batteries: The batteries required are three Burgess W30BP or equivalent and one Burgess F2BP or equivalent. A compartment is provided in the case of the instrument for holding all batteries. A set of batteries is supplied with the instrument.

Mounting: The instrument is supplied in a walnut case with cover and is mounted on an engraved black crackle-finish aluminum panel.

Dimensions: With cover closed, (length) 11 x (width) 6⅝ x (height) 5⅞ inches, over-all.

Net Weight: 9¾ pounds, including batteries.

Type		*Code Word*	*Price*
728-A	D-C Vacuum-Tube Voltmeter. .	PILOT	$110.00

MUTUAL INDUCTANCE MEASUREMENT WITH THE TYPE 650-A IMPEDANCE BRIDGE

● IN BOTH THE LABORATORY and the factory, the TYPE 650-A Impedance Bridge provides a rapid means of checking inductors, capacitors, and resistors with an accuracy sufficient for nearly all commercial requirements. In addition, this bridge can be adapted for many specialized measurements beyond the scope of its original design. A good example is furnished by a problem recently encountered in the measurement of the mutual inductance of automotive ignition coils and magnetos.

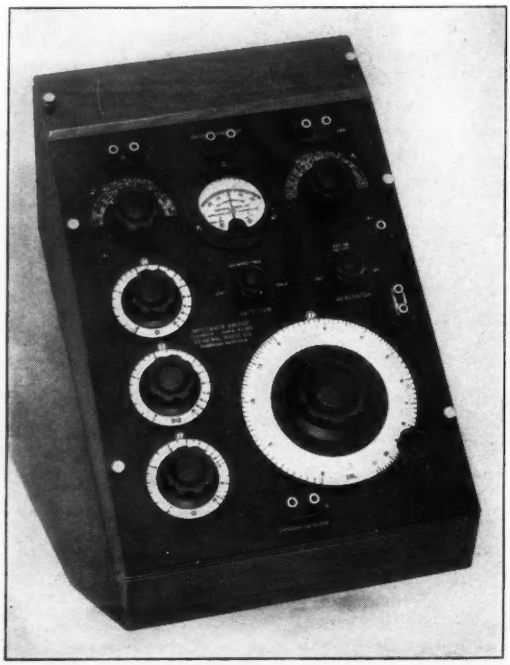


FIGURE 1. View of the TYPE 650-A Impedance Bridge.

A TYPE 650-A Impedance Bridge was available for this measurement, and a consideration of the circuit showed that the instrument could easily be converted

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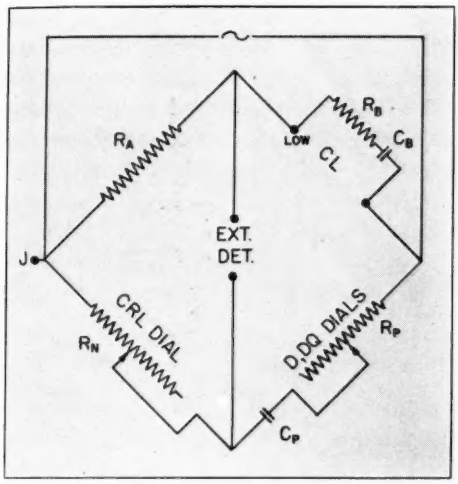


FIGURE 2. Schematic circuit diagram for the TYPE 650-A Impedance Bridge as used for capacitance measurements.

to a Carey-Foster type of mutual inductance bridge.*

The schematic bridge circuit for *capacitance* measurements is shown in Figure 2. To convert to a Carey-Foster bridge, the A-arm is shorted, and the unknown inductor and an external resistor are connected as shown in Figure 3. Shorting of the A-arm is accomplished by connecting the junction J to the high EXT DET terminal or to the low CL terminal. One winding of the ignition coil is connected to the CL terminals in series with the external resistor. The other winding is placed in series with the head telephones. The external resistor may, for convenience, be a decade resistance box of 100,000 ohms maximum setting. A known fixed resistor of suitable magnitude is equally satisfactory.

Balance is obtained by varying the CRL dial and either the D or the DQ dial. The mutual inductance, M, is then given by

$$M = R_N(R_B + R_L)C_P$$

*Other methods of measuring mutual inductance were discussed in an article by R. F. Field, "The Measurement of Mutual Inductance," General Radio *Experimenter*, January, 1937.

where R_N is the reading of the CRL dial multiplied by 1000, R_B is the external resistor in the B-arm, R_L is the effective resistance of the inductor, and C_P is the capacitance of the standard mica condenser in the P-arm, 10^{-8} farads.

The inductance of the winding connected in the P-arm can be determined from the expression

$$L = (R_N + R_P)(R_B + R_L)C_P.$$

The resistance R_P depends upon the setting of the D or DQ dial at balance. The choice of the dial to be used is determined by the resistance needed for balance. The maximum resistance of the D dial is 1650 ohms, while that of the DQ dial is 16,500 ohms. The magnitude of R_P is calculated from the expression

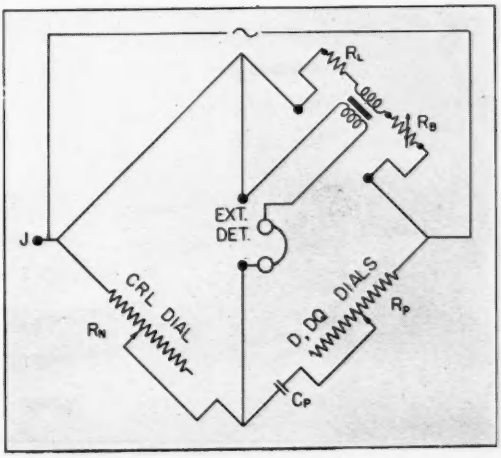
$$R_P = \frac{D}{6.28 \times 10^{-5}}$$

where D is the dial reading multiplied by the factor indicated by the multiplier switch setting.

The resistance, R_B, of the decade box should be large compared to R_L, the effective resistance of the coil under measurement, so that R_L can be neglected. For this condition,

$$M = R_N R_B C_P$$

FIGURE 3. Modification of the circuit of Figure 2 for measurements of mutual inductance.



and

$$L = (R_N + R_P)(R_B C_P).$$

When R_L is not negligible compared to R_B, the inductance and storage factor Q of the coil can be first measured with the bridge connected for inductance measurement, and the value R_L then calculated.

In the particular application referred to above, the measurement of ignition coils, it was found that the low tension coil should be connected to the P-arm of the bridge in order that balance be within range of the bridge controls.

— L. E. PACKARD

CHICAGO DISTRICT OFFICE
920 South Michigan Avenue

● **AS MANY OF OUR READERS** in the Chicago area know, the General Radio Company has been operating an Engineering and Sales Office since December 1, 1943, on South Michigan Avenue. Mr. L. E. Packard from our Cambridge engineering staff is in charge, and is already well known to many of our Chicago friends. Mr. Packard is thoroughly acquainted with the uses and applications of General Radio products, and is always glad to pass along technical information gained through his experience in the measurement field. The facilities of the office are available not only to our customers in greater Chicago, but to all in the Mid-West area who find it more convenient to communicate with

View of the interior of the General Radio Company's Chicago Office.

our Chicago office than with the main office at Cambridge.

A demonstration laboratory is maintained in which many of our latest instruments may be inspected and tested under operating conditions. New equipment will be on display as it becomes available. Arrangements can also be made to have some of the smaller instruments demonstrated in customers' plants.

Our office in Chicago is in a position to give valuable and prompt assistance regarding price and delivery, as well as to advise regarding Government restrictions on the purchase of equipment.

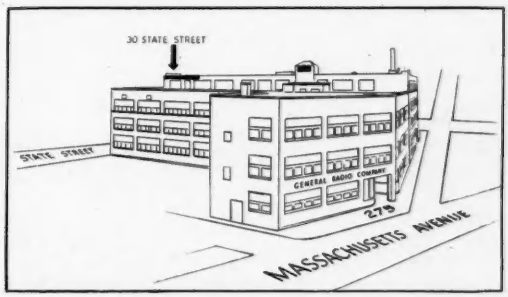
Occasionally an engineering conference meeting at the office on a subject of interest to a particular group of engineers will be arranged. Space permits a maximum of about fifty people to be accommodated. Meetings on the subject of sound and vibration, as well as on new broadcast station monitoring equipment, were held early in October of this year.

Mr. Packard is often able to offer suggestions that are useful in keeping General Radio equipment in satisfactory operating condition, or, when repairs are necessary, to arrange for the work to be done at our factory. A small shop for minor emergency repair work is maintained at Chicago.

Parking space, an important consideration in congested cities, is available at the rear of the office building, and may be used by visitors who wish to drive to the Chicago office.

MISCELLANY

● **TO THOSE WHO CALL** on us at our new address the accompanying sketch may be helpful. It shows our new front door in relation to our old one.

Congratulations to W. L. Everitt on his election to the presidency of the Institute of Radio Engineers. Dr. Everitt's recent article in the *Proceedings of the I. R. E.* on engineering education has proved a timely one, and has stimulated a good deal of discussion. At a recent meeting of the Boston Section, representatives of both education and industry gave their views on the subject for over two hours, with plenty of people asking to be heard when the meeting adjourned.

The nature and behavior of dielectrics is a subject of considerable importance to the radio engineer, and research on dielectrics has naturally been stimulated by the war. One of the leaders in this field is General Radio's Robert F. Field, who has delivered several papers on the subject before technical societies. His latest: "The Behavior of Dielectrics Over Wide Ranges of Frequency and Temperature," at a meeting of the Basic Science Group of the A.I.E.E. at New York on November 9, 1944. We hope to